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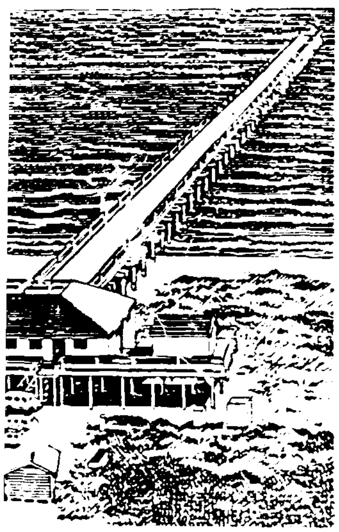

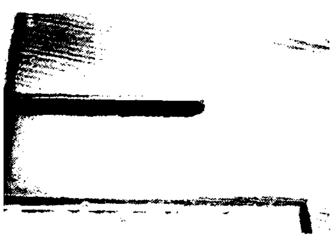

TECHNICAL REPORT CERC-91-4

(2)

WAVE CONDITIONS FOR PROPOSED HARBOR DEVELOPMENT IN LOS ANGELES OUTER HARBOR, LOS ANGELES, CALIFORNIA, SUPPLEMENTAL TESTS

Coastal Model Investigation

by

Robert R. Bottin, Jr., Hugh F. Acuff

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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May 1991

Final Report

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and

Port of Los Angeles, Harbor Department
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COASTAL ENGINEERING RESEARCH CENTER

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13. ABSTRACT *(Maximum 200 words)*

A 1:100 scale (undistorted) hydraulic model of Los Angeles Outer Harbor, California, was used initially to investigate short-period storm wave conditions for proposed harbor development located near the Angel's Gate entrance. The model reproduced the proposed harbor expansion, Angel's Gate entrance, portions of the existing breakwaters, and sufficient bathymetry in San Pedro Bay to permit generation of the required test waves. The model was reactivated to determine the optimum plan for protection of the south mooring area (from locally generated waves in the harbors' complex) if the adjacent Port of Long Beach and/or the Pactex landfills are not constructed initially. An 80-ft-long electro-hydraulic, unidirectional, spectral wave generator and an automated data acquisition and control system were used in model operation. It was concluded from the model investigation that:

(Continued)

14. SUBJECT TERMS
See reverse.

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13. ABSTRACT (Continued).

a. The southern container terminal berthing areas, without breakwater protection (Plan 25), will be subjected to hazardous wave conditions for locally generated wind waves from the easterly direction (3.6-sec, 3.2-ft and 4.2-sec, 4.9-ft incident waves). Wave heights up to 5.0 ft will occur in the berthing areas.

b. The 2,300-ft-long breakwater (Plan 26) will result in wave conditions within the established 2.0-ft wave height criterion in all but one mooring location. The criterion will be exceeded at this location by 0.2 ft for extreme storm conditions (4.2-sec, 4.9-ft waves) that will occur about 8.8 hr per year.

c. The 2,100-ft-long breakwater (Plan 28) will result in waves substantially exceeding the criterion at one mooring area for extreme storm conditions. For less severe storm conditions (3.6-sec, 3.2-ft waves), the established 2.0-ft wave height criterion would be met at all mooring locations.

d. The 800-ft-long breakwater (Plan 32) will result in wave heights within the established criterion at all but one mooring location for less severe storm conditions. The criterion will be exceeded by only 0.2 ft at this location. For extreme wave conditions, wave heights will significantly exceed the criterion except in the northernmost berthing locations.

14. SUBJECT TERMS (Continued).

Breakwaters
Harbors, California
Hydraulic models
Los Angeles and Long Beach Harbors, California
Short-period storm waves
Wave protection

PREFACE

A request for additional testing on the existing Los Angeles Outer Harbor model was initiated by the Port of Los Angeles in coordination with the US Army Engineer District (USAED), Los Angeles. Authorization for the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), to perform the study was subsequently granted by Headquarters, US Army Corps of Engineers. Funds were provided by the Port of Los Angeles and authorized by USAED, Los Angeles, on 2 July 1990.

Model testing was conducted at WES during the period November-December 1990 by personnel of CERC under the direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Chief and Assistant Chief, CERC, respectively; and under direct supervision of Messrs. C. E. Chatham, Jr., Chief, Wave Dynamics Division (WDD), and Dennis G. Markle, Chief, Wave Processes Branch (WPB). The tests were conducted by Mr. Hugh F. Acuff, Civil Engineering Technician, under the supervision of Mr. Robert R. Bottin, Jr., Project Manager. This report was prepared by Messrs. Bottin and Acuff and typed by Ms. Debbie S. Fulcher, WPB.

During the course of the investigation, liaison was maintained by means of conferences and telephone communications. Messrs. John Warwar and Dick Wittkop, Port of Los Angeles, visited WES to observe model operation and participate in a conference.

Initial test results for the model were reported in WES Technical Report CERC-89-13, "Wave Conditions for Proposed Harbor Development in Los Angeles Outer Harbor, Los Angeles, California; Coastal Model Investigation," dated December 1989. Test results for supplemental wave conditions are reported herein.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres
square miles (US statute)	2.589998	square kilometres

WAVE CONDITIONS FOR PROPOSED HARBOR DEVELOPMENT IN LOS ANGELES OUTER HARBOR, LOS ANGELES, CALIFORNIA

SUPPLEMENTAL TESTS

Coastal Model Investigation

PART I: INTRODUCTION

Background

1. The ports of Los Angeles and Long Beach are located in San Pedro Bay along the southern coast of California (Figure 1). They have, historically, experienced long-period surge activity which occasionally results in mooring difficulties for ships berthed in various locations within the harbors' complex. In coordination with the US Army Corps of Engineers (Corps), the Ports of Los Angeles and Long Beach are conducting studies for harbor development and expansion to accommodate future needs. Descriptions of the existing breakwaters may be found in Bottin (1988).

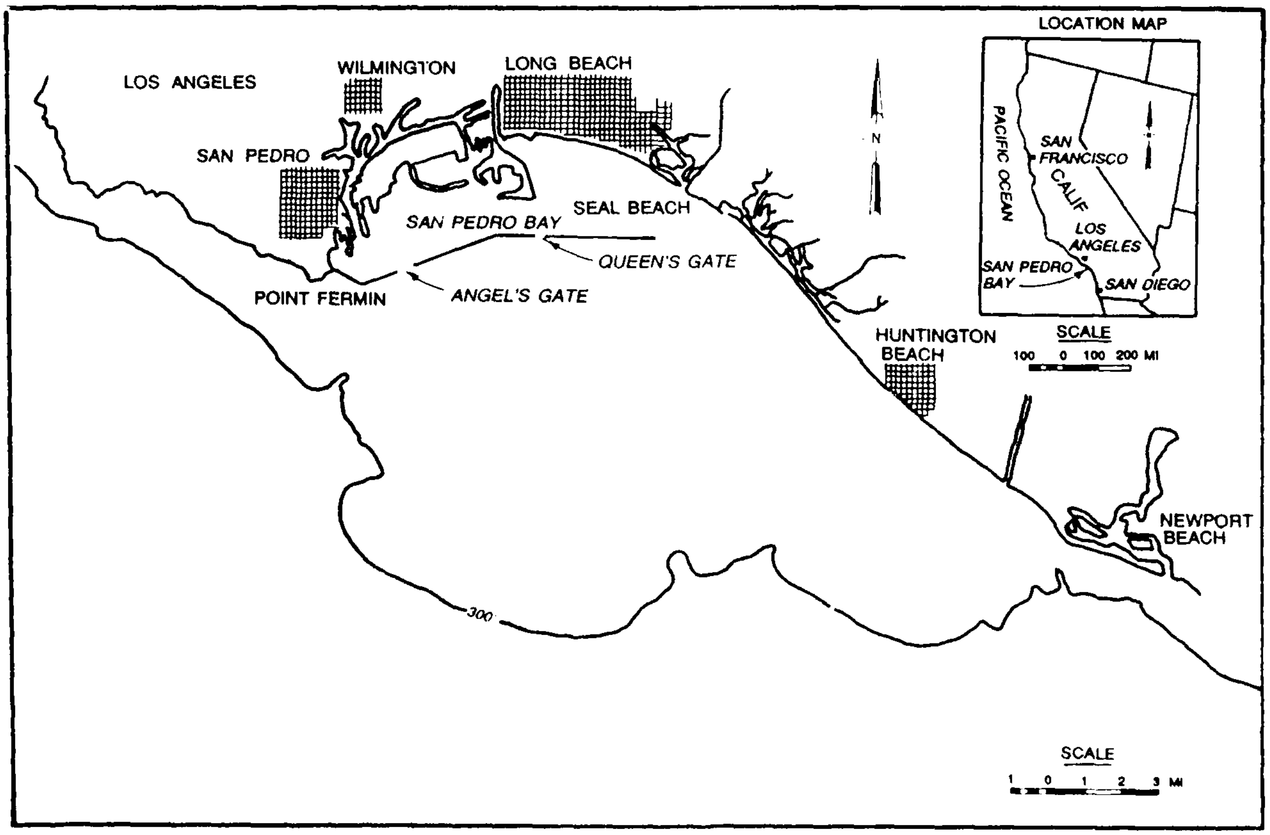

Figure 1. Project location

2. A distorted model (scale, 1:400 horizontal, 1:100 vertical) of the Los Angeles-Long Beach Harbors' complex was designed and constructed at the US Army Engineer Waterways Experiment Station (WES) in the early 1970's and is being used to determine the effects of long-period waves (30 to 400 sec) which lead to resonant harbor oscillations that can cause ship loading-unloading problems and downtime. The model distortion and scales, however, are inappropriate for short-period (3 to 25 sec) wind wave testing.

Model Study Objectives

3. At the request of the Port of Los Angeles, in coordination with the US Army Engineer District, Los Angeles (SPL), an undistorted hydraulic model, which includes a portion of Los Angeles Outer Harbor (Figure 2), was designed and constructed by WES' Coastal Engineering Research Center (CERC) to:

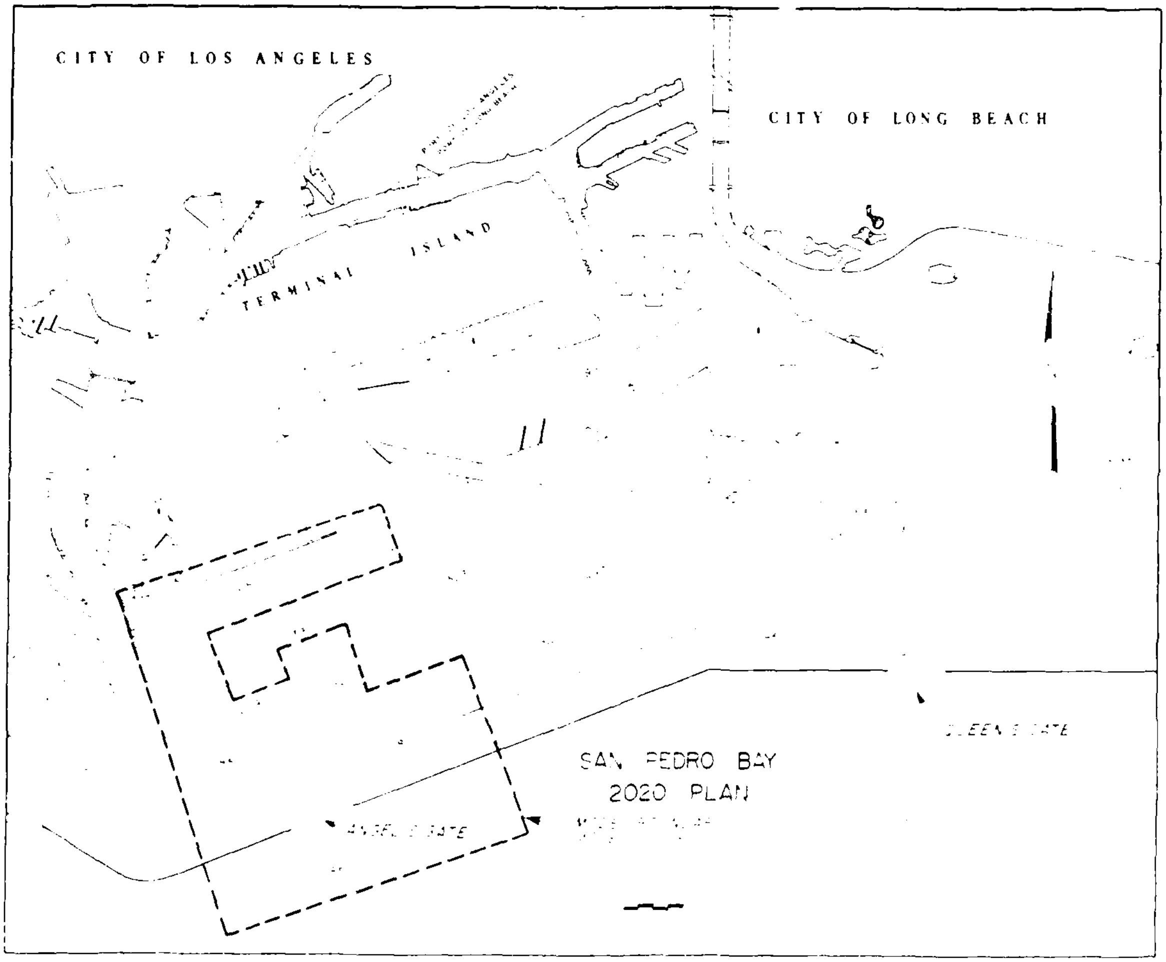

Figure 2. Approximate limits of model relative to harbor

a. Determine short-period wave conditions in the entrance, in vessel maneuvering areas, and in berthing areas of the container ship and tanker terminals, during periods of storm-wave activity for proposed harbor development located near Angel's Gate.

b. Develop remedial plans to improve wave conditions as found necessary.

c. Determine if design modifications to the proposed plans could be made that would significantly reduce construction costs and still provide adequate protection.

Previously Reported Model Tests and Conclusions

4. The original purpose of the Los Angeles Outer Harbor model was to investigate short-period storm wave conditions for proposed harbor development located near the Angel's Gate entrance. Details of the investigation were published (Bottin and Tolliver 1989), and conclusions derived from results of those tests are shown below. Plan numbers refer to those in the initial investigation.

a. The originally proposed outer harbor expansion plan (Plan 1) will result in wave heights that will exceed the established criteria of 6.0 ft* in the tanker terminal and 1.5 ft in the container terminal a small percentage of the time. Maximum wave heights obtained were greater than 10 and 4 ft in the tanker and container terminals, respectively. The criterion will be exceeded on an average of 7.35 hours per year in the tanker terminal and 21.45 hours per year in the container terminal.

b. Sealing of the Middle Breakwater (Plan 5) will result in slightly improved wave conditions in the container terminal of the outer slip for test waves from 209 and 154 deg.

c. A 200-ft westerly extension of the Middle Breakwater (used for several test plans) will slightly, but not significantly, reduce wave heights in vessel terminal areas.

d. Decreasing the navigation width between the proposed landfill and Middle Breakwater from 1,200 to 1,000 ft (Plan 8) will not significantly reduce wave heights at the terminals; however, an increase of the navigation opening to 1,400 ft (Plan 22) will substantially increase wave conditions in these areas.

e. The 1,800-ft-long San Pedro Breakwater spur in conjunction with a 200-ft westerly extension of the Middle Breakwater (Plan 14) will result in wave heights that exceed the established

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* A table of factors for converting no-SI units of measurement to SI (metric) units is presented on page 3.

criterion in the container terminal and that meet the criterion in the tanker terminal areas. Maximum wave heights obtained in the container terminal were about 3 ft, but the criterion at this location will be exceeded on an average of only about 4.65 hours per year.

f. The installation of vertical walls in the southern slip (Plan 19) will result in very rough and confused wave conditions in the container terminal due to wave reflections with wave heights up to 9 ft at this location.

g. Reducing the southern slip basin width from 1,000 to 800 ft (Plan 20) will result in wave heights that exceed the established criterion in the container and tanker terminals; however, wave heights were of less magnitude than the original Plan 1 expansion configuration and the criteria would be exceeded a smaller percentage of the time. Maximum wave heights were 8.2 and 2.6 ft in the tanker and container terminals, respectively. It is estimated the established 1.5-ft criterion in the container terminal would be exceeded on an average of 3.45 hours per year, and the 6.0-ft criterion in the tanker terminal exceeded about 4.2 hours per year.

h. The revetted/vertical wall northern slip configuration (Plan 24) will result in the established 1.5-ft wave-height criterion being exceeded by only 0.2 ft at one mooring location for only one wave condition. This condition will occur on an average of only 0.15 hour per year.

Purpose of the Current Investigation

5. At the request of the Port of Los Angeles and SPL, the hydraulic model of Los Angeles Outer Harbor was reactivated by CERC to determine wave conditions and the optimum plan for protection of the southern container slip from locally-generated wind waves within the harbors' complex. The model was revised under guidance from the Port of Los Angeles and SPL. It was assumed that initially the proposed landfills in the adjacent Port of Long Beach and the Pactex landfill would not be constructed. When constructed, these landfills would provide protection to the slip from local wind waves generated within the harbor.

Wave-Height Criteria

6. Absolute criteria have not yet been developed for acceptable wave conditions that will ensure satisfactory mooring conditions in harbors during attack by waves. For this study, however, the Port of Los Angeles and SPL

specified that for an improvement plan to be acceptable, maximum wave heights were not to exceed 2.0 ft at the container terminal locations in the southern slip of the harbor.

PART II: MODEL

Design of Model

7. The Los Angeles Outer Harbor Model (Figure 3) was constructed to an undistorted linear scale of 1:100, model to prototype. Scale selection was based on such factors as:

- a. Depth of water required in the model to prevent excessive bottom friction.
- b. Absolute size of model waves.
- c. Available shelter dimensions and area required for model construction.
- d. Efficiency of model operation.
- e. Available wave-generating and wave-measuring equipment.
- f. Model construction costs.

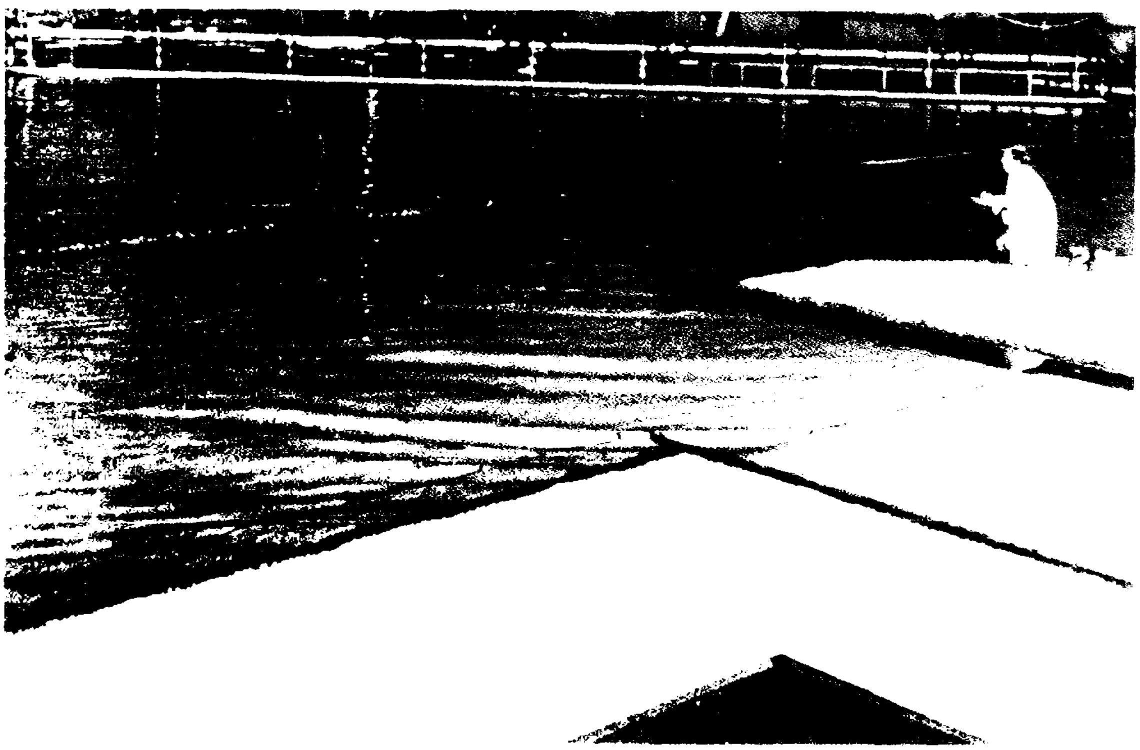

Figure 3. General view of model

A geometrically undistorted model was necessary to ensure accurate reproduction of short-period wave patterns including the effects of wave refraction, diffraction, and reflection. Following selection of the linear

scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension*	Model-Prototype Scale Relations
Length	L	$L_r = 1:100$
Area	L^2	$A_r = L_r^2 = 10,000$
Volume	L^3	$\forall_r = L_r^3 = 100,000$
Time	T	$T_r = L_r^{1/2} = 1:10$
Velocity	L/T	$V_r = L_r^{1/2} = 1:10$

* Dimensions are in terms of length (L) and time (T).

8. The existing breakwaters and proposed revetments at Los Angeles Harbor are rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, the transmission and absorption of wave energy became a matter of concern in design of the 1:100-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (Le Méhauté 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations (Dai and Jackson 1966, Brasfeild and Ball 1967) at WES, this adjustment was made by determining the wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A cross-section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at Los Angeles, it was determined that close approximation of the correct wave-energy transmission characteristics would be obtained by increasing the size of the rock used in the 1:100-scale model to approximately two times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the

Los Angeles model, the rock sizes were computed linearly by scale, then multiplied by 2 to determine the actual sizes to be used in the model.

The Model and Appurtenances

9. The model, which was molded in cement mortar, reproduced the proposed harbor expansion, Angel's Gate entrance, 2,800 and 5,100 ft of the San Pedro and Middle Breakwaters, respectively, and underwater contours in San Pedro Bay to an offshore depth of 60 ft with a sloping transition to the wave generator pit elevation* of -100 ft. The total area reproduced in the model was approximately 27,500 sq ft, representing about 10 square miles in the prototype. A model layout is shown in Figure 4. Vertical control for model construction was based on mean lower low water (mllw). Horizontal control was referenced to a local prototype grid system.

10. Prototype wave conditions were reproduced in the model by an 90-ft-long, unidirectional spectral wave generator with a trapezoidal-shaped, vertical motion plunger. The electrohydraulic wave generator utilized a hydraulic power supply, and the vertical motion of its plunger was controlled by a computer-generated command signal. The controlled movement of the plunger caused water displacements which reproduced the required test waves. The wave generator was mounted on retractable casters which enabled it to be positioned to generate waves from the required directions.

11. An automated data acquisition and control system (ADACS), designed and constructed at WES was used to generate and transmit control signals, monitor wave generator feedback, and secure and analyze wave data at selected locations in the model. Basically, through the use of a MICROVAX computer, ADACS recorded onto magnetic disks the electrical output of parallel-wire, resistance-type wave gages that measured the change in water-surface elevation with respect to time. The magnetic disc output of ADACS then was analyzed to obtain the wave data.

12. A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

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* All elevations (el) cited herein are in feet referred to as mean lower low water (mllw) unless otherwise noted.

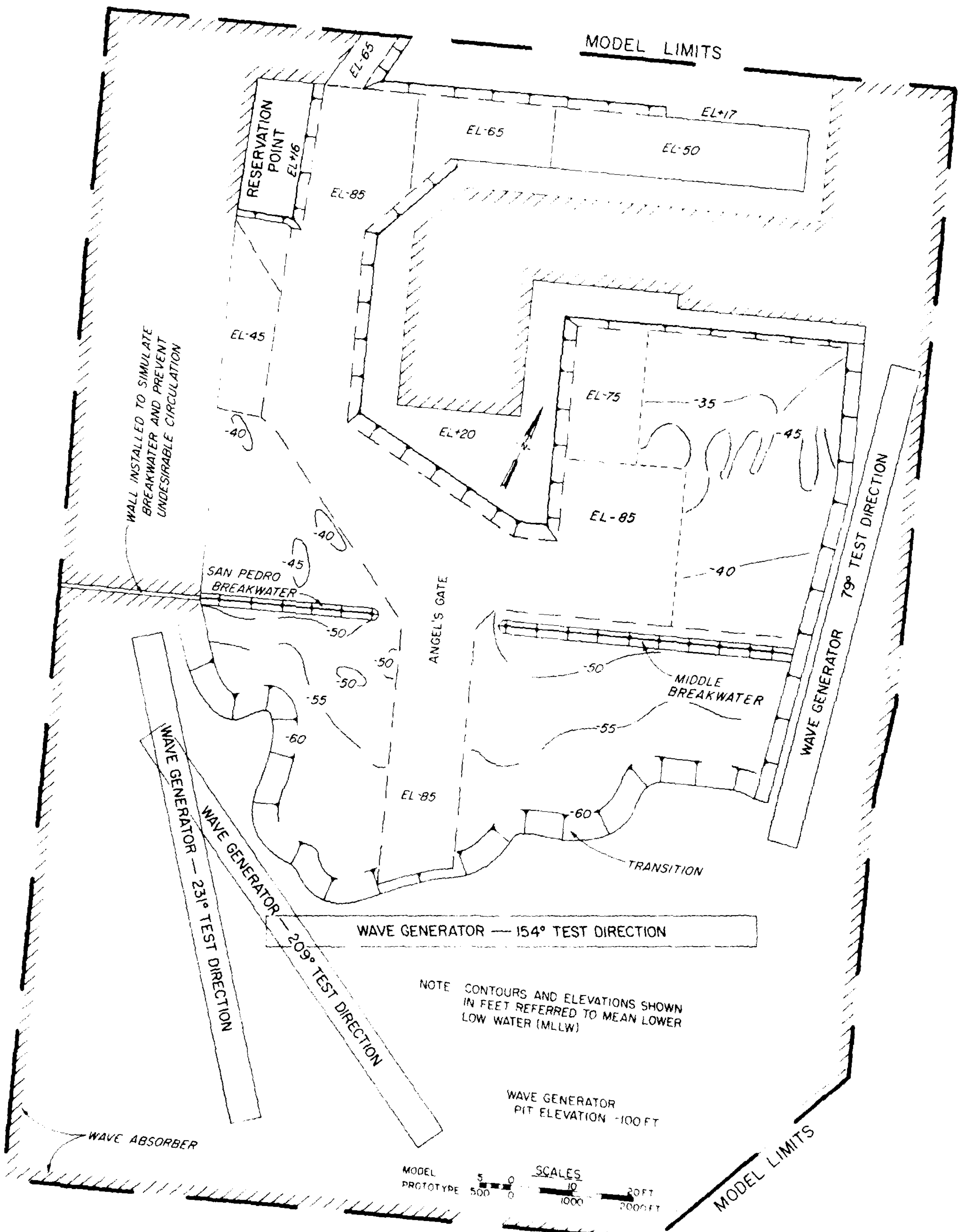


Figure 4. Model layout

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Test Conditions

Still-water level

13. Still-water levels (swl's) for harbor wave action models are selected so that the various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the project area, the overtopping of harbor structures by the waves, the reflection of wave energy from various structures, and the transmission of wave energy through porous structures.

14. In most cases, it is desirable to select a model swl that closely approximates the higher water stages which normally occur in the prototype for the following reasons:

- a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.
- b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind tide and shoreward mass transport.
- c. The selection of a high swl helps minimize model scale effects due to viscous bottom friction.
- d. When a high swl is selected, a model investigation tends to yield more conservative results.

15. An swl of +5.5 ft was selected by the Port of Los Angeles and SPL for use during model testing. This value (+5.5) represents mean higher high water in Los Angeles Outer Harbor.

Factors influencing selection of test wave characteristics

16. In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and directions for the test waves that will allow a realistic test of proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed

continues to blow, and the distance over the water (fetch) which the wind blows. Selection of test wave conditions entails evaluation of such factors as:

- a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can attack the problem area.
- b. The frequency of occurrence and duration of storm winds from the different directions.
- c. The alignment, size, and relative geographic position of the navigation entrance to the harbor.
- d. The alignments, lengths, and locations of the various reflecting surfaces inside the harbor.
- e. The refraction of waves caused by differentials in depth in the area seaward of the harbor, which may create either a concentration or a diffusion of wave energy at the harbor site.

Wave refraction

17. When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. The change in wave height and direction may be determined by conducting a wave-refraction analysis. The shoaling coefficient, a function of wave length and water depth, can be obtained from the Shore Protection Manual (1984). When the refraction coefficient is determined, it is multiplied by the shoaling coefficient and gives a conversion factor for transfer of deepwater wave heights to shallow-water values.

18. Refraction and shoaling coefficients were obtained at Los Angeles Harbor for various wave periods from several deepwater wave directions for the initial test series. For this test series, however, a wave refraction analysis was not conducted due to the limited fetch from which waves can be generated from easterly directions. The magnitude and direction of winds were considered to be the governing factors and waves were assumed to be locally generated. The critical direction of wave approach was determined to be from 79 deg (measured clockwise from true north) for these tests.

Selection of test waves

19. Deepwater wave data were obtained from several sources for the original test series, but for these tests, wave conditions representative of

this area were obtained by the application of hindcasting techniques from the Shore Protection Manual (1984) to wind data acquired at Long Beach Harbor during the period 1974-1981. Model test waves selected from these data are shown below:

Direction deg	Wave Period sec	Wave Height ft
79	3.6	3.2
79	4.2	4.9

Based on the hindcasting techniques, it was estimated that the 3.6-sec waves would occur approximately 43.8 hours per year, and the 4.2-sec wave conditions about 8.8 hours per year. Unidirectional wave spectra (based on TMA parameters) for the selected test waves were reproduced for this test series.

Analysis of Model Data

20. Relative merits of the various plans tested were evaluated by a comparison of wave heights at selected locations in the model, and visual observations and wave pattern photographs. In the wave-height data analysis, the average height of the highest one third of the waves (H_s) recorded at each gage location was computed. All wave heights then were adjusted to compensate for excessive model wave-height attenuation due to viscous bottom friction by application of Keulegan's equation (Keulegan 1950)*. From this equation, reduction of wave heights in the model (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel.

* G. H. Keulegan, 1950. "The Gradual Damping of a Progressive Oscillatory Wave with Distance in a Prismatic Rectangular Channel," unpublished data, National Bureau of Standards, Washington, DC, prepared at request of Director, WES, Vicksburg, MS, by letter of 2 May 1950.

PART IV: TESTS AND RESULTS

Tests

Test plans

21. Wave height tests were conducted for several test plan variations most of which consisted of changes in the length of a breakwater installed to provide wave protection to the proposed southern berthing area. Wave pattern photographs were obtained for test waves with some of the plans installed. With the exception of the landfill in the southeastern portion of the outer harbor, all plans tested entailed the original outer harbor expansion of the ports 2020 Plan. Brief descriptions of the improvement plans are presented in the following subparagraphs; dimensional details are shown in Plate 1.

a. Plan 25 consisted of the original harbor expansion but the landfills in the southeastern portion of the outer harbor (Long Beach and PACTEX landfills) were removed and replaced with existing outer harbor bathymetry.

b. Plan 26 included the elements of Plan 1 with a 2,300-ft-long breakwater installed adjacent and to the east of the southern berthing area. The breakwater was at the western limit of the proposed landfill and may be used as revetment when future landfill construction starts.

c. Plan 27 entailed the elements of Plan 26 but 300 ft of the seaward end of the breakwater was removed which resulted in a 2,000-ft-long structure.

d. Plan 28 involved the elements of Plan 26 but 200 ft of the seaward end of the breakwater was removed which resulted in a 2,100-ft-long structure.

e. Plan 29 consisted of the elements of Plan 26 but 600 ft of the seaward end of the breakwater was removed which resulted in a 1,700-ft-long structure.

f. Plan 30 entailed the elements of Plan 26 but 900 ft of the seaward end of the breakwater was removed which resulted in a 1,400-ft-long structure.

g. Plan 31 involved the elements of Plan 26 but 1,200 ft of the seaward end of the breakwater was removed which resulted in an 1,100-ft-long structure.

h. Plan 32 included the elements of Plan 26 but 1,500 ft of the seaward end of the breakwater was removed which resulted in an 800-ft-long structure.

Wave height tests and wave patterns

22. Wave height tests for the various plans of improvement were obtained for test waves listed in paragraph 19 and wave gage locations shown in Plate 1. Wave pattern photographs were secured for representative test plans to provide documentation of test results.

Test Results

23. In evaluating test results, the relative merits of the various plans were based on an analysis of measured wave heights in the proposed mooring area. Model wave heights (significant wave height or $H_{1/3}$) were tabulated to show measured values at selected locations.

Test plans

24. Results of wave-height tests conducted for Plans 25-32 are presented in Table 1. Maximum significant wave heights were 5.0, 2.2, 4.2, 3.9, 4.4, 4.2, 4.3, and 3.9 ft in the berthing areas (Gages 3-6) for Plans 25-32, respectively. Wave patterns obtained for representative test plans are shown in Photos 1-4.

Discussion of test results

25. Results of wave height tests with the existing contours and the absence of the PACTEX and Long Beach landfills (Plan 25) indicated that wave heights ranging from 3.6 to 5.0 ft will occur in the container terminal berthing areas (Gages 3-6) for the more severe 4.2-sec, 4.9-ft locally generated wind wave conditions from the easterly direction.

26. Wave height tests for the original 2,300-ft-long breakwater (Plan 26) revealed that a maximum sisgnificant wave height of 2.2 ft would occur at the most southern berth (Gage 3) for the 4.2-sec, 4.9-ft incident wave conditions. The established 2.0 ft criterion was exceeded by 0.2 ft, and the condition will occur approximately 8.8 hours per year. Wave conditions in other areas of the basin were well within the established criterion.

27. Wave height tests for the 2,100-ft-long breakwater (Plan 28) indicated that the lesser storm wave conditions (3.6-sec, 3.2-ft) would result in wave conditions in the berthing areas within the established criterion. Severe storm conditions would result in wave heights up to 3.9 ft at the southern berth (Gage 3) an average of approximately 8.8 hours per year. Wave conditions in other areas of the basin were well within the specified criterion.

28. Results of wave height tests for the 800-ft-long breakwater (Plan 32) revealed that the lesser storm waves would result in wave conditions within the 2.0 ft criterion in the inner (northern) berths (Gages 4-6), but waves in the southern berth would exceed the criterion by 0.2 ft. For severe storm conditions, waves up to 3.9 ft in height will occur in all but the northernmost berths (Gages 5 and 6).

PART V: CONCLUSIONS

29. Based on test conditions and results of the hydraulic model investigation reported herein, it is concluded that:

a. The southern container terminal berthing areas, without breakwater protection (Plan 25), will be subjected to hazardous wave conditions for locally-generated wind waves from the easterly direction. Waves up to 5.0 ft will occur in the berthing areas.

b. The 2,300-ft-long breakwater (Plan 26) will result in wave conditions within the established 2.0-ft wave height criterion in all but one mooring location. The criterion will be exceeded at this location by 0.2 ft for extreme storm conditions (4.2-sec, 4.9-ft incident waves) that will occur about 8.8 hours per year.

c. The 2,100-ft-long breakwater (Plan 28) will result in waves substantially exceeding the criterion at one mooring area for extreme storm conditions. For less severe storm conditions (3.6-sec, 3.2-ft waves), however, the established 2.0-ft wave height criterion would be met at all mooring locations.

d. The 800-ft-long breakwater (Plan 32) will result in wave heights within the established criterion at all but one mooring location for less severe storm conditions. The criterion will be exceeded by only 0.2-ft at this location. For extreme wave conditions, however, wave heights will significantly exceed the criterion except in the northernmost berthing locations.

REFERENCES

Bottin, R. R., Jr. 1988. "Case Histories of Corps Breakwater and Jetty Structures; Report 1, South Pacific Division," Technical Report REMR-CO-3, Repair, Evaluation, Maintenance, and Rehabilitation Research Program, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bottin, R. R., Jr., and Tolliver, L. R. 1989. "Wave Conditions for Proposed Harbor Development in Los Angeles Outer Harbor, Los Angeles, California; Coastal Model Investigation," Technical Report CERC-89-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brasfeild, C. W., and Ball, J. W. 1967. "Expansion of Santa Barbara Harbor, California; Hydraulic Model Investigation," Technical Report No. 2-805, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dai, Y. B., and Jackson, R. A. 1966. "Design for Rubble-Mound Breakwaters, Dana Point Harbor, California; Hydraulic Model Investigation," Technical Report No. 2-725, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Le Méhauté, B. 1965. "Wave Absorbers in Harbors," Contract Report No. 2-122, prepared by National Engineering Science Company, Pasadena, CA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shore Protection Manual. 1984. 4th ed., 2 vols, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC.

Stevens, J. C., et al. 1942. "Hydraulic Models," Manuals of Engineering Practice No. 25, American Society of Civil Engineers, New York.

Table 1

Wave Heights for Plans 25-32

Test Wave Period sec	Test Wave Height ft	Wave Height*, ft, Gage Number 1	2	3	4	5	6	7	8	9
					Plan 25					
3.6	3.2	2.5	1.6	1.8	2.5	2.8	2.6	2.6	2.5	2.9
4.2	4.9	3.7	3.5	3.6	4.3	5.0	4.3	4.8	3.9	4.5
					Plan 26					
3.6	3.2	2.3	2.2	1.2	0.3	0.2	0.1	3.1	2.9	3.5
4.2	4.9	3.6	3.9	2.2	0.5	0.2	0.2	4.7	4.2	4.3
					Plan 27					
3.6	3.2	2.3	2.2	2.3	0.4	0.2	0.1	2.9	2.7	3.5
4.2	4.9	4.0	3.9	4.2	0.8	0.3	0.2	4.5	4.7	4.8
					Plan 28					
3.6	3.2	2.1	2.5	2.0	0.4	0.2	0.1	2.8	3.2	3.3
4.2	4.9	3.8	4.5	3.9	0.8	0.4	0.2	4.7	4.8	5.0
					Plan 29					
3.6	3.2	2.3	2.3	2.3	0.8	0.2	0.2	3.2	3.3	3.5
4.2	4.9	3.8	4.2	4.4	1.2	0.5	0.3	4.4	4.8	4.9
					Plan 30					
3.6	3.2	2.1	2.2	2.3	1.3	0.2	0.2	2.7	2.5	2.7
4.2	4.9	3.7	3.5	4.2	2.5	0.5	0.2	4.2	4.2	4.5
					Plan 31					
3.6	3.2	2.2	2.2	2.4	1.7	0.3	0.2	2.8	2.6	2.8
4.2	4.9	3.9	3.8	4.3	3.3	0.6	0.4	4.6	4.2	4.3
					Plan 32					
3.6	3.2	2.1	2.2	2.2	2.0	0.4	0.2	2.9	2.6	2.6
4.2	4.9	3.4	4.2	3.8	3.9	0.9	0.5	4.5	4.0	4.1

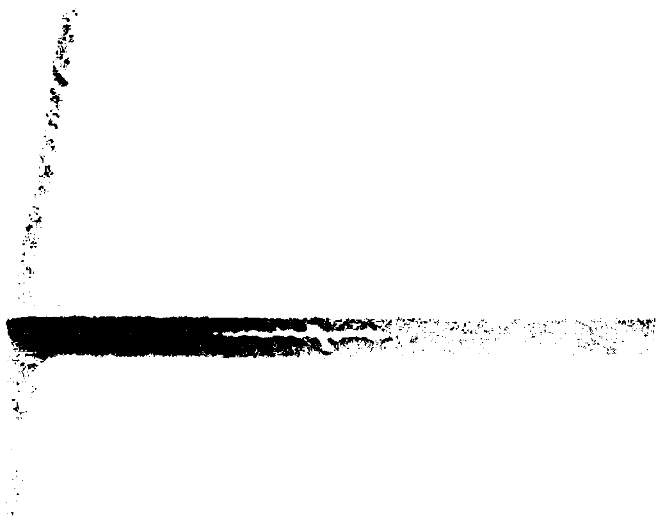
* (Significant wave heights or $H_{1/3}$)

a. 3.6-sec, 3.2-ft test waves

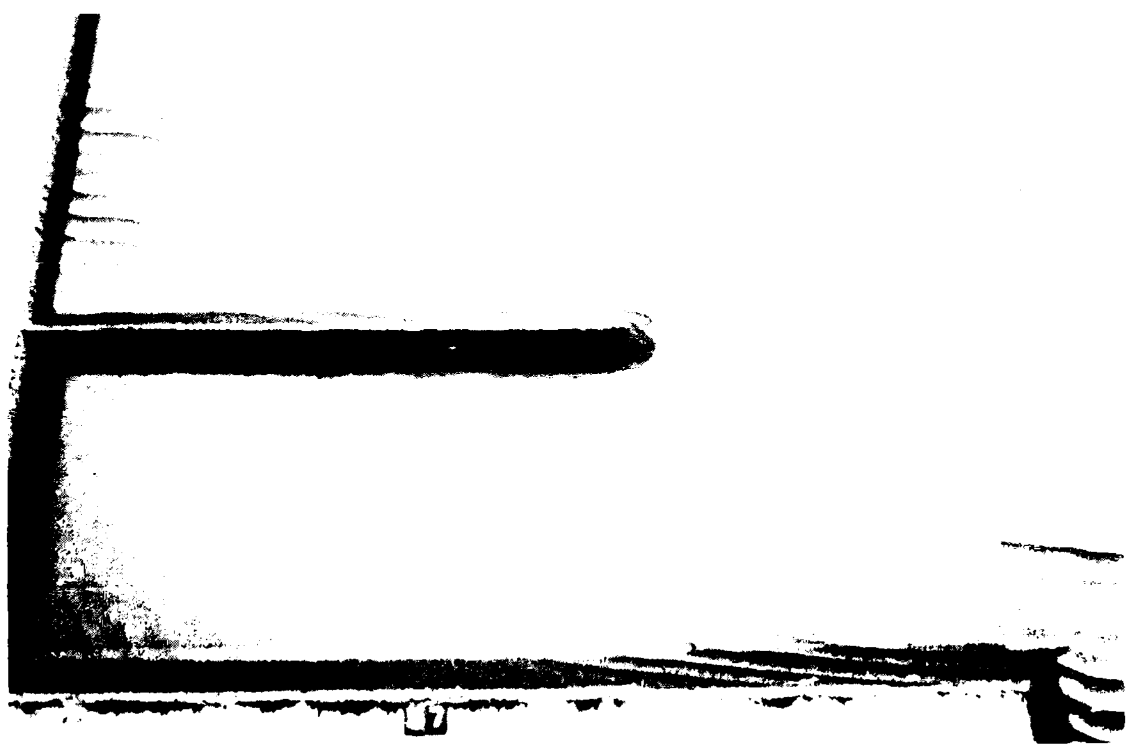
b. 4.2-sec, 4.9-ft test waves

Photo 1. Typical wave patterns for Plan 2 (looking east)

a. [illegible] sec, 3.[illegible]-ft test waves

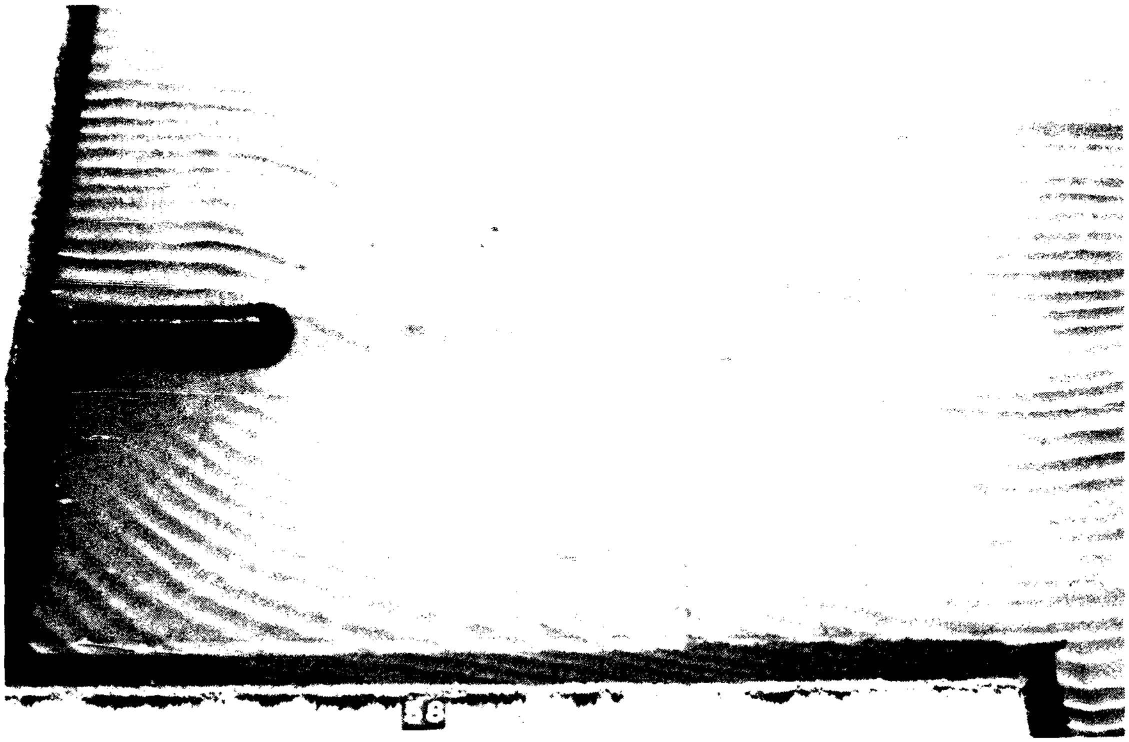


a. 3.6-sec, 3.2-ft test waves



b. 4.2-sec, 4.9-ft test waves

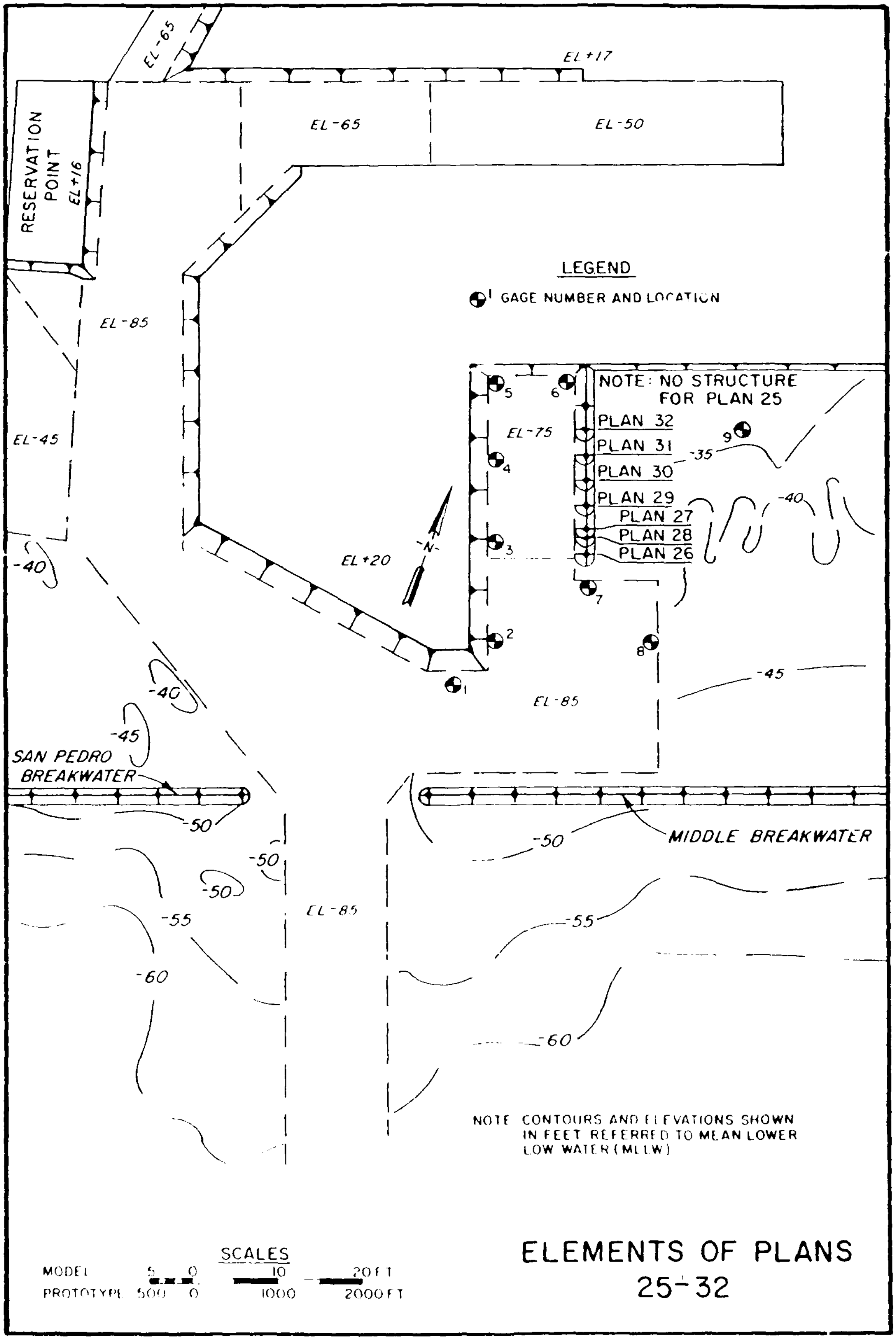
Photo 3. Typical wave patterns for Plan 28 (looking east)



a. 3.6-sec, 3.2-ft test waves

b. 4.2-sec, 4.9-ft test waves

Photo 4. Typical wave patterns for Plan 32 (looking east)



EL-65
EL+17
EL-65
EL-50
RESERVATION POINT
EL+16
LEGEND
GAGE NUMBER AND LOCATION
EL-85
NOTE: NO STRUCTURE FOR PLAN 25
PLAN 32
PLAN 31
PLAN 30
PLAN 29
PLAN 27
PLAN 28
PLAN 26
EL-75
EL-45
-35
-40
EL+20
N
-40
-40
EL-85
-45
-45
SAN PEDRO BREAKWATER
MIDDLE BREAKWATER
-50
-50
-50
-50
-55
-55
EL-85
-60
-60
NOTE CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 5 0 10 20 FT
PROTOTYPE 500 0 1000 2000 FT
ELEMENTS OF PLANS 25-32